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Fluctuation Phenomena

or

The Physics of "Noise"

by

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Definition

From Dictionary

1. Any undesired sound.
2. Any unwanted disturbance in a communication channel within a given bandwidth.

From A. van der Ziel

Spontaneous fluctuations in current, voltage, or temperature that sets the lower limit on measurements taken on a system under test.

The word "noise" comes from the fact that if a fluctuating voltage is amplified by a low-frequency amplifier and fed into a speaker it produces a hissing sound.

Physical noise is produced by stochastic processes and therefore can be modeled mathematically as random variables.

1 Classification of Noise Phenomena

In this section I will summarize K. M. van Vliet's views on how to divide noise phenomena into broad groups which are based on four principles. They are:
(1) The principle of thermal equilibrium. This allows noise to be characterized as **thermal** or **nonthermal**.
(2) The principle of **microscopic** versus **mesoscopic** fluctuations. The term "mesoscopic" is used for quantities which are governed by the master equation for coarse-grained variables, these quantities being themselves fluctuations of macroscopic variables.
(3) The principle of **lumped** versus **distributed** representation. Also we could speak of discrete versus continuous random processes or even of finite dimensional versus infinite dimensional Markovian random processes.
(4) The principle of **classical** versus **quantum** nature of the noise. Of course van Vliet believes that only quantum processes exit in nature. However, some allow for a classical description and others do not. Note that in quantum statistical mechanics there is both statistical and quantum mechanical uncertainty. If both occur, we speak of quantum noise.

2 Types of Noise

1. **Thermal Noise** is due to the random motion of carriers in any conductor due to the ambient heat energy. This is an equilibrium process and *does not require* current flow.
2. **Shot Noise** occurs whenever a phenomenon can be considered as a series of independent events occuring at random. This occurs for carriers falling through a potential in one direction *only*. This is a non-equilibrium process and *requires* DC current flow. First seen in tubes.
3. **g-r Noise** (generation-recombination) occurs whenever free carriers are generated and recombine in a semiconductor material. Usually small at room temperature, can be seen at liquid Nitrogen temperature (77K).
4. **Flicker Noise** is one name given to noise which has a frequency distribution proportional to $1/f^\alpha$ with α close to unity. First seen in tubes where it gets its name due to the apparent waxing and waneing (flickering) of the filament glow. There are various known causes, some possible theories for others and some totally unknown. Other names include Excess Noise, Low-Frequency Noise and $1/f$ noise for the case of $\alpha = 1$.
5. **Burst Noise** (Popcorn Noise) is a type of low-frequency noise which varies as $1/f^2$ at higher frequencies. The mechanism is not fully understood, but the source is related to the

presence of heavy-metal ion contamination, such as gold. These ions create deep-level energy traps (near the mid-bandgap). Burst Noise is so named for the fact that an oscilloscope track of this type of noise shows burst of noise on a number (2 or more) of discrete levels. The repetition rate or the noise pulse is in the audio frequency range and produces a "popping" sound when played through a speaker, leading to its alternate name. Recently seen in very small area MOSFETs with very clean gate oxides (1 or 2 trap energies). Random Telegraph Noise is another name for this case.

6. **Hot Electron Noise** (Hot Carrier Noise): White noise due to lattice heating by carrier collisions. Important in short channel MOSFETs. Increases the thermal noise over the classical limit. This happen just before avalanche breakdown and significant I_{sub} begins to flow.

7. **Avalanche Noise**: Produced by Zener or avalanche break-down in a pn junction. The holes and electrons in the depletion region must acquire enough energy to create hole-election pairs by colliding with the lattice. This process is multiplicative and results in the production of a random series of noise spikes. This noise is what you get in a MOSFET with significant substrate current. Has a white spectrum.

8. **Temperature-Fluctuation Noise**: Noise of a small body occurs because of the fluctuating heat exchange between the body and its enviornment due to fluctuations in the omitted and received radiation and to fluctuations in the heat conduction. Generally too small to be important.

9. **Quantum $1/f$ Noise**: This is the frontier of noise research. Very small, usually masked by other $1/f$ noise sources. Has been measured in pentodes.

3 $1/f$ Noise

Some $1/f$ Noise Sources

1. Current in Carbon Composition resistors
2. Current in Thin Metal Films (in the past, not today)
3. Current in Ionic Solutions
4. All Solid-State components; but especially Si MOSFET, GaAs MESFET
5. Body Sway
6. The Earth's wobble on its axis
7. Magnitude of Ocean waves
8. Magnitude of Earthquakes
9. Magnitude of Thunder Storms
10. Magnitude of Tornados

11. Magnitude of Hurricanes
12. Classical and Jazz Music
13. Economic data

Some $1/f$ Noise Physical Models

1. Grain Boundary Structures
2. Generation-Recombination (g-r)
3. Trapping in oxides (especially MOSFET's)
4. Thermal Fluctuations
5. "Quantum" Noise
6. Random Switches (Avalanche diode; Micro plasmas)
7. Mobility Fluctuations due to Acoustical Phonons

Causes (Mechanisms) of $1/f$ Noise - ?

1. Normal g-r processes
2. Trapping in Semiconductors
3. Defects in semiconductors